Consumptive Water Use in Response of Carnations to Three Irrigation Regimes[1]

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Abstract. Carnations planted in November, 1965, were watered when soil moisture suction reached 0.04 bar, 0.6 bar and 10K ohms resistance (ca 20–50 bars), the latter measured with gypsum blocks. Yield was found to be highest for the 0.04 bar treatment. Mean grade was consistently higher for this treatment than the other 2 treatments throughout the flowering period. The results were mainly due to increased side shoots and longer internode lengths of cut flowers grown at suctions below 0.04 bar. Keeping life was reduced, but dye uptake was enhanced by growing carnations with frequent irrigations. Consumptive water use increased from 120.9 cm for the 10K ohm treatment to 184.7 cm for the 0.04 bar treatment, exceeding the water equivalent of solar radiation outside the greenhouse. However, there was no significant effect on water required per cut flower or on efficiency, whether the latter was based on total yield or dry weight. It was concluded that maximum production would occur where soil moisture stress is zero and internal plant stress is as close to zero as possible, provided other factors were favorable.

Introduction

FEW reports deal with response of greenhouse plants to water supply and to the amount of water necessary to achieve that response. In a recent monograph, Lunt and Seeley (16) make only brief reference to water required. There is little published information on consumptive water use and evapotranspiration relationships of plants grown commercially in greenhouses in the U.S.A. Such studies have been conducted largely by European workers (14, 18, 19, 20). It has been suggested (7) that the growth potential for greenhouse cultivation in arid regions is high, and that the water utilization by crops in greenhouses should be determined, as well as means whereby efficiency of water use may be increased.

Numerous studies (e.g. 1, 5, 9) have been conducted on plant response to moisture regimes, with variable results, and, as a general rule, ranges of soil suction as measured with tensiometers have been suggested for carnations (9). Variable plant response to soil moisture regimes alone would be expected since the stress to which a plant is subjected is largely the function of both supply and transpirational demand (2, 12, 21). There has been adverse comment where internal plant water potential has not been measured (4, 15). However, it was the purpose of this investigation not only to consider plant response, but to obtain immediate information on consumptive water use, and to suggest the direction of future research.

Methods and Materials

The experimental design and equipment have been described (8). Essentially, 18 lysimeters were arranged linearly on 2 benches, with buffer plots between each lysimeter. Each plot had a steel container under it to catch drainage water. The amount lost from each plot was determined between 8 and 12 hr following an irrigation. Water was applied to the upper soil surface by a modified drip-tube system. Watering continued until the plot began to drain. The amount applied was metered, so that by subtraction of the quantity lost through drainage, which occurred over an 8 to 12 hr period, the volume retained for evapotranspiration could be determined.

Irrigation treatments were selected to bracket the possible extremes. Five plots were watered when soil suction, as measured with porous cup tensiometers, reached 0.04 bar (wet), 5 when suction reached 0.6 bar (medium), and 5 when electrical resistance, as measured with gypsum blocks reached 10K ohms (dry). Fig. 1 shows the relationship between suction and moisture content for the soil. Undisturbed core samples, taken at 10K ohms, showed moisture contents between 0.06 and 0.1 cc/cc. This would indicate suctions in excess of 20 bars (Fig. 1). It is not known that such high ranges actually occurred during the investigation, although Slatyer (21) has

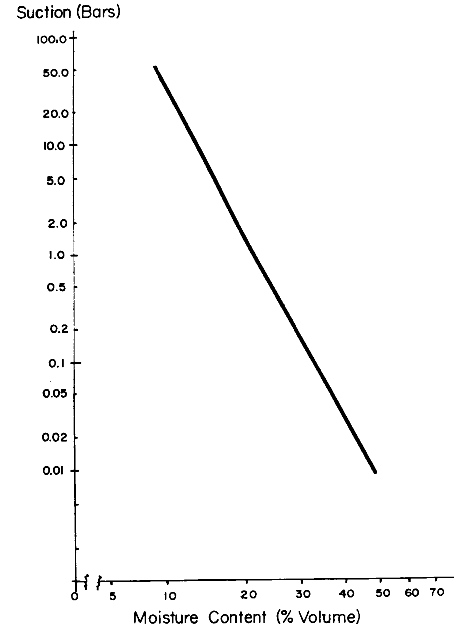

Fig. 1. Relationship between soil moisture suction and moisture content of a 1–1–1 mixture, Ft. Collins loam, sand and leaf mold. The line represents the computed regression with a coefficient of 98.7.

shown that some plants may extract moisture from soils at suctions higher than 20 bars.

The soil was a 1–1–1 mixture of Ft. Collins loam, sand and leaf mold, 12.5 cm deep. Cuttings, cv 'White Pikes Peak', were planted, 24 plants per plot, on November 24, 1965, given a single pinch, and the experiment terminated on August 26, 1966. General cultural procedures outlined by Holley and Baker (10), were followed. Nutrients, at the following rates per 1000 gal, were injected into the watering line at each irrigation: 1) NH_4NO_3, 3 lb.; 2) KCl, 1.30 lb.; 3) $NaNO_3$, 0.25 lb.; 4) K_2SO_4, 0.40 lb.; 5) 11–30–0, 0.75 lb.; and 6) Borax, 0.5 oz.

Measurements of plant response included: 1) total flowers cut, 2) mean grade calculated by assigning the numbers 2 through 5 to each of 4 possible cut flower grades with 5 highest (fancy, standard, short and design in descending order), 3) keeping life in the manner described by Hanan (6), fresh and dry weights of standard grade carnations, 5) dye uptake of cut flowers, 6) leaf width on the fifth pair below the calyx, 7) internode length on the fifth internode below the calyx, 8) the number of leaf pairs on a standard grade cut flower, 9) stem strength by measuring the degrees of bending from the horizontal of standard grade flowers, and 10) the number of side shoots formed following pinching and the number of secondary side shoots formed at the time

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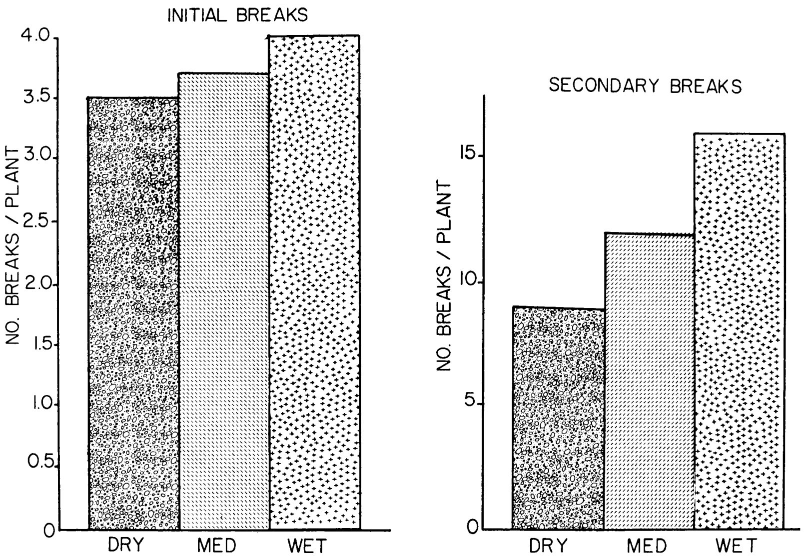

Fig. 3. Effect of 3 irrigation regimes on number of initial and secondary side shoots produced by carnations. Treatments consisted of watering when soil suctions reached 0.04 bar (wet), 0.6 bar (medium) and 10K ohms resistance (dry).

of flower cutting during the first production peak.

Results

Plant response.

Response was characterized by higher yield and grade the more frequently carnations were watered. Plants in the wet treatment did show some incipient chlorosis, attributed to deficient aeration, but this was insufficient to affect yield. Frequent irrigation hastened flowering (Fig. 2), particularly during the second peak production period. Increased yield was attributed to increased number of side shoots during initial growth, this being compounded in the formation of secondary side shoots for the second crop (Fig. 3). Flower quality, as indicated by mean grade, was consistently higher for the wet treatment (Fig. 2). The higher grade resulted largely from longer stems produced by the wet treatment. Higher moisture levels had the effect of producing longer internodes (Table 1), with no decrease in stem strength. As a result, there was a distinct change in the distribution of grades in each treatment (Table 2).

Keeping life of flowers obtained from the wet plots was decreased slightly (Table 1). The significant difference of 0.5 day was considered, for practical purposes, to be commercially negligible. Dye uptake of cut flowers, however, was markedly enhanced at high irrigation frequencies (Fig. 4).

Table 2. Per cent of each grade produced by carnations subjected to 3 irrigation treatments for 9 months.

Treatment[a]	Grade			
	Fancy	Standard	Short	Design
	(5)	(4)	(3)	(2)
10K......	4.5	71.1	21.5	2.9
0.6.......	10.6	78.4	9.8	1.2
0.04......	40.1	53.7	5.5	0.7

[a]Treatments consisting of watering when soil moisture suction reached 0.04 bar, 0.6 bar and 10K ohms resistance.

Table 1. Effect of 3 irrigation regimes for 9 months on growth and flowering of carnations.

Measurement	Treatment[a]			HSD[b]
	0.04	0.6	10K	
Yield				
Total cut flowers..........................	1335	1067	858	76
Per ft^2 (9 mo.)............................	37.8	30.2	24.3	
Mean grade................................	4.27	3.97	3.71	0.10
Mean fresh weight per standard grade cut flower (g)...............................	19.9	19.5	19.1	0.4
Mean dry weight per standard grade cut flower (g)...............................	3.81	3.91	3.81	0.02
Per cent dry weight.........................	19.1	20.1	19.9	
Leaf width (mm)...........................	11.9	11.8	11.0	0.1
Internode length (cm)........................	11.3	10.1	9.9	0.6
Number of leaf pairs per standard grade cut flower..................................	6	6	6	———
Keeping life (days)..........................	6.4	6.8	7.2	0.5
Stem strength (degrees bending from horizontal)..	8.7	8.7	8.9	———

[a]Carnations irrigated when soil moisture suction reached 0.04 bar, 0.6 bar and 10K ohms resistance.
[b]Tukey's honestly significant difference.

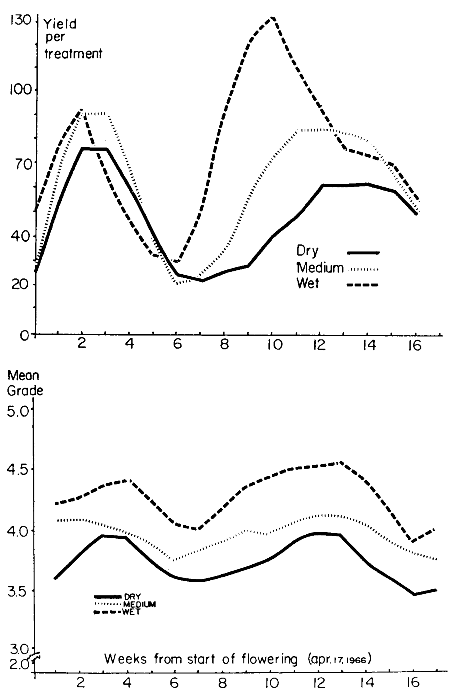

Fig. 2. Upper: Cut flower production of carnations subjected to 3 irrigation regimes, expressed as total number of flowers cut per treatment. The left and right peaks indicate the first and second peak production periods respectively, as the result of a single pinch. *Lower:* Effect of 3 irrigation regimes on carnation cut flower mean grade. Treatments consisted of watering when soil suction reached 0.04 bar (wet), 0.6 bar (medium) and 10K ohms (dry).

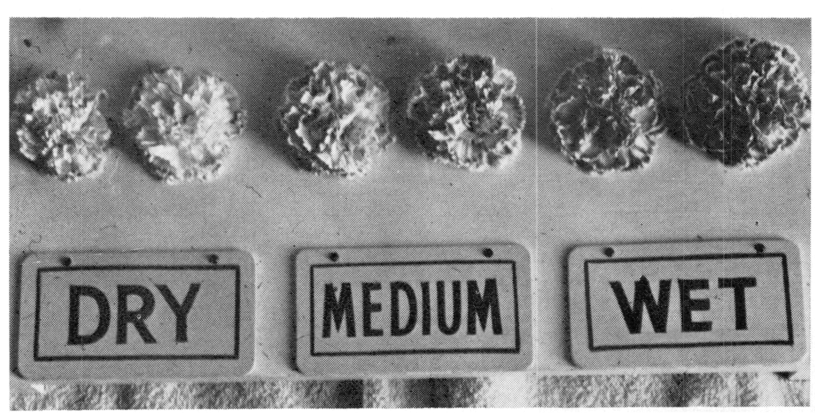

Fig. 4. Effect of 3 irrigation regimes on dye uptake by carnation flowers. Treatments consisted of watering when soil suction reached 0.04 bar (wet), 0.6 bar (medium) and 10K ohms resistance (dry).

Table 3. Water utilization by carnations subjected to 3 irrigation regimes for 9 months, expressed as cm equivalent depth of water (1 gal ft^{-2} = 1.04 cm water depth).

Measurement	Treatment[a] 0.04	0.6	10K	HSD[b] (5%)
Mean number of irrigations per treatment	65	43	32	9
Total water applied	184.7	153.9	120.9	3.8
Total water retained	132.7	112.3	87.5	2.1
Total water lost by drainage	52.0	41.7	33.5	1.5
Mean volume applied per application	2.9	3.6	3.8	

[a]Carnations watered when soil moisture suction reached 0.04 bar, 0.6 bar and 10K ohms resistance.
[b]Tukey's honestly significant difference.

Consumptive water use.

Fig. 5 shows the mean number of days between irrigations during the experimental period. During initial stages of growth, the interval varied between 20 and 30 days, gradually decreasing to relatively short intervals during a period of high solar radiation and large plants. Although there was a 10-day difference between treatment extremes in watering interval during December, the difference in amount of water supplied was less than one qt ft^{-2} (10.4 mm equivalent water depth). The differences between minimum and maximum quantities applied during the course of the experiment were about 5-fold for the dry treatment and approximately 7½-fold for the wet treatment (Fig. 5).

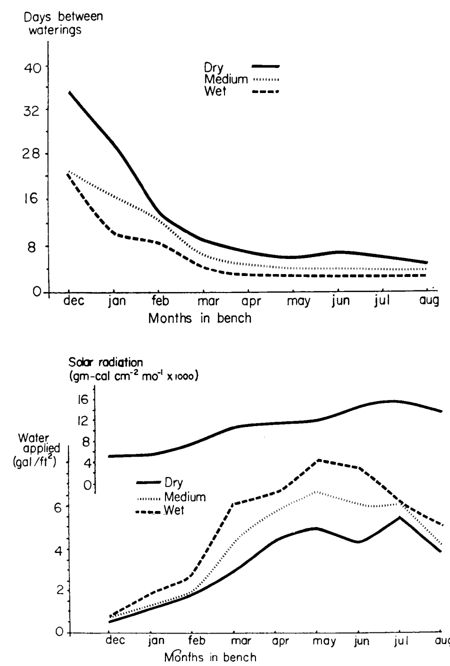

Fig. 5. Upper: Variation in irrigation interval during the growth of carnations subjected to 3 irrigation regimes, treatments begun December, 1965. *Lower:* Effect of 3 irrigation regimes on quantity of water applied to carnations and compared with total solar radiation as measured with an Epply pyranometer. Treatments consisted of watering when soil suction reached 0.04 bar (wet), 0.6 bar (medium) and 10K ohms resistance (dry).

The water applied, retained in the plots, and drained from the treatments are given in Table 3. Table 4 presents the results of a number of calculations on data given in Tables 1 and 3. The differences as to water applied or retained per cut flower were not remarkable, and it was concluded that, under conditions of this experiment, yield of carnations was proportional to the water supplied. It made no difference whether calculations were based on water applied or retained, indicating that water lost through drainage was proportional to the number of irrigations. Similarly, calculation of efficiency, either on the basis of yield or dry weight, apparently was not influenced by the irrigation regime.

Discussion

The maximum water supply at which a significant decrease in yield would occur was not obtained. There were indications that the 0.04 bar treatment was approaching the borderline, e.g. chlorosis, insignificant decreases in dry weight and water utilization per cut flower. Even though internal plant water potential was not measured, it was possible to assume that improvement in yield and grade resulted largely from lower plant water potential as the result of a higher water supply to the root system. We hypothesize that maximum carnation growth will occur when soil water potential is zero and plant water potential is as close to zero as possible—provided all other conditions are suitable. Gates (2) suggested that maximum growth will occur when leaf potential is somewhat less than zero (i.e. higher stress). However, we argue, on the basis of these results and those of others (13, 17), that decreases in growth or transpiration or both at high soil moisture levels have been caused by deficient aeration. Maximum water uptake, under any given environmental situation, should occur when soil water potential at the root-root substrate interface is zero. Thus, of course, omits consideration of osmotic potentials of the soil solution.

Even if it were possible to increase soil water potential to zero, it is doubtful that plant water potential would also be zero under conditions suitable for maximum photosynthesis. Transpiration requires a potential gradient from soil solution to the air. Secondly, the attempt to reduce stress by increasing water supply may be self-defeating. Kowalzcyk (11) showed that transpiration rates of carnation leaves increase as soil water supply increases, in part due to decreased stomatal resistance to water vapor diffusion. Carnations adapted to high soil moisture regimes are likely to experience higher stress when compared, under identical conditions, to plants adapted to low moisture regimes.

Prorating the maximum water applied on a monthly basis and computing the possible consumptive use for a year results in a maximum possible water use of 246 cm. For snapdragons (5), the amount has been calculated as 369 cm, assuming complete ground cover. This exceeds the consumptive water use of most field crops in temperature climates, neglecting losses in storage and delivery.[4] Despite high water utilization, water remains one of the cheapest raw materials in green-

Table 4. Miscellaneous computations on water utilization by carnations subjected to 3 irrigation regimes for 9 months, based on Tables 1 and 3, and expressed as gallons and cm equivalent depth of water.

Calculation	Treatment[a] 0.04 gal	0.04 cm	0.6 gal	0.6 cm	10K gal	10K cm
Mean volume water applied to treatment per flower	1.20	4.89	1.25	5.09	1.22	4.97
Mean volume water retained in plot per flower	0.86	3.50	0.91	3.71	0.88	3.59
Water ratio[b]	879		884		857	
Efficiency (yield)[c]	22.0		21.1		21.6	
Efficiency (dry weight, %)	83.8		82.5		82.3	

[a]Carnations watered when soil moisture suction reached 0.04 bar, 0.6 bar and 10K ohms resistance.
[b]Water ratio based on total dry weight production, using mean standard grade dry weight. This does not include weight of material removed in training and pruning the plants.
[c]Efficiency calculated on the basis of yield divided by total water applied.
[d]Efficiency calculated on the basis of total mean, standard grade dry weight divided by water applied.

[4]In reviewing the manuscript, Dr. R. J. Hanks pointed out that evapotranspiration in this study exceeded the water equivalent of net radiation. Total solar radiation as measured with an Epply pyranometer outside the greenhouse was 99,097 cal cm^{-2}. At 20°C, this is equivalent to 169.4 cm water (see

house production as long as it is readily available and of reasonable quality. In arid regions, where there is likely to be severe competition between industrial, domestic and agricultural users for available water supplies, the position of protected horticulture is outstanding.

The results suggest that significant yield improvements in the future are likely to result from control of plant water potential, and that increases in efficiency of water utilization will require additional information on energy relationships between the plant and its aerial environment in the greenhouse.

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Table 3); a figure that assumes there was no transmission loss through the greenhouse cover, and all energy was utilized in evapotranspiration. It appears logical to assume that advective sensible heat and large vegetational surface areas were important in influencing water loss.

Comparison of Sampling Methods for the Determination of Seasonal Changes in the Nutrient Content of Apple Leaves[1]

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Abstract. In studies of seasonal trends in apple leaf nutrients, 5 different seasonal leaf sampling methods using the same shoots of young and old apple trees have been compared with a sampling of mid-shoot leaves on different shoots each sampling date to determine whether there would be any differences in leaf P, K, Ca and Mg trends. Sampling methods resulted in significant interaction with the check only in data for leaf concentration of Ca. The methods which were compared with the check had average seasonal leaf concentrations of P, K, Ca and Mg which differed significantly from the check in a few instances. They also produced slightly to considerably lower coefficients of variation than the check in 78 of 100 possible comparisons. This makes such methods very desirable as alternative sampling procedures where they do not otherwise vary from the standard.

Introduction

IN determining the seasonal trend in concentration of inorganic nutrients in leaves of young apple trees, it may be necessary to take leaf samples repeatedly from the same terminal shoots. The same situation may exist with older trees fruiting freely from terminal buds. No direct information is available showing the best sequence for sampling such shoots or, whether there is any difference resulting from the seasonal pattern of leaf sampling.

A number of papers have presented results from which one would infer that manner of leaf sampling sequentially on the same shoots might make a difference in the seasonal curve of nutrient concentration. Beyers (2) and Lilleland and Brown (6) showed that certain inorganic nutrients varied in concentration in peach leaves at different positions on a shoot on a single date. Myers and Brunstetter (8) obtained similar information in an analysis of tung leaves. Presumably by utilizing different shoots on each sampling date, Drosdoff (3) working with tung and Emmert (4,5) with apple determined that the relative seasonal change in nutrient concentration of leaves at different positions on a shoot depends on the element and, in the latter reference, on the season. Mason (7) sampled, and chemically analyzed, leaves from Malling VII whips in a nursery row. Different, randomly-selected, whips were used on each sampling date. His results, which are presented in considerable detail, show that relative changes through the season developed in 7 elements at different, precisely defined leaf positions on the shoots.

Rogers et al. (9) departed from the usual procedure of sampling leaves on different shoots on successive dates. Their technique consisted of punching disks from the same leaves at each sampling time. These authors stated that this manner of sampling gave results very similar to the usual sampling method. However, it required numerous terminals because of the small amount of tissue obtained on each date from each shoot.

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